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Effects of soil physical properties on erodibility and infiltration parameters of selected areas in Gidan kwano

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Abstract

This study looked at the physical properties of soil of selected areas of Gidan Kwano campus of Federal University of Technology Minna, Nigeria and their effects on erodibility and infiltration parameters. Infiltration rate of the selected areas were conducted using a double ring infiltrometer and soil samples collected at different depths of 0 – 30 and 30 – 60 cm respectively. Collected samples were analyzed to determine physical properties such as moisture content, particles size, bulk density, porosity and organic matter. Textural classification was carried out to determine the percentage dominance of the various soil types present in the selected areas. Plot A has a steady infiltration rate after $1\frac{1}{2}$ hour at 0 cm/hr. While plot B had a steady infiltration rate after 30 minutes at 1cm/hr. The soil moisture count for plot A ranged between 9.54% to 14.56% while that of plot B range between 10.64% to 11.26%. The particle sizes analysis indicated that the soil type in plot A is mainly medium loam and predominantly sand clay loam in plot B. It is therefore concluded that, the study area is susceptible to erosion because of poor infiltration rate.

Keywords: Erodibility, Erosion, Infiltration, Soil, Undisturbed, Water
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Introduction

Soil is an essential input to agricultural production and in Nigeria, where agricultural Production is crucial to development and the livelihoods of the majority of the population depend on this natural abundant resource (Idah *et. al*., 2008). Agricultural land use in Nigeria often results in the degradation of natural soil fertility and reduced productivity (Onweremadu, *et. al*., 2007). Soil degradation under farming sometimes brings about soil erosion, sedimentation and leaching (Obalum *et al*., 2011; Wang *et. al*., 2013). With the current rate of soil loss through various agents of erosion, there will be a rapid displacement of the top soil resource into the sea, ocean, rivers and streams. In Nigeria, low crop production has been linked partly to the poor soil condition caused by past severe erosion (Morgan *et. al.*, 2011).

Soil erosion occurs when soil particles are carried off by water or wind and deposited else where (Longpichai, 2013; Wang *et al*., 2013). Erosion begins when rain or irrigation water detaches soil particles (Kashi *et al*., 2014). Montgomery (2007), Idah *et al*., (2008) and sRomkens *et. al.*, (2013) stated that when there is too much water on the soil surface, it fills surface depressions and begins to flow with enough speed; this surface runoff carries away the loosed soil. Soil erosion depends on the erosivity of the rainfall and the erodibility of the soil (Chris-Emenyonu and Onweremadu, 2011; Igwa *et al*., 2013; Olotu *et al*., 2013). Extent of washing away of soil particles depends on its characteristics and particles involved, which leads to the concept of erodibility (Singh and Khera, 2008; Idah *et al*., 2008). Agents of soil erosion are basically water and wind, each contributing a significant amount of loss each year under various land used condition.

Soil erodibility is an estimate of the ability of soil to resist erosion based on the physical characteristics of each soil (Harris *et al.*, 2012). Generally, soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion (Leonard *et. al*., 2006; de Oliveira *et al*., 2014).

A soil with relatively low erodibility factor may show signs of serious erosion, yet a soil could be highly erodible and surfed little erosion. This is because soil erosion is a function of many factors as stated in the Universal Soil Loss Equation (USLE) (de Oliveira *et. al*., 2014). These factors include rainfall (R), soil erodibility factor (K), slope length (LS), crop factor (C) and control practice factor (P). This is represented in the universal soil loss equation as:

$$A = R\ K\ LS\ C\ P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Soil erodibility factor K is a quantitative expression of the inherent susceptibility of a particular soil to erode at different rates when other factors affecting erosion are standardized (Ezeabasili1 *et. al.,* 2014). Erodibility varies with soil textures, aggregates, stability, shear strength, soil structures, infiltration capacity, soil depth, bulk density, soil organic matter and chemical constituents. Soils below the plough layers are often compact and less erodible. Rills will develop in areas where resistance bedrock is close to the surface if the parent material is unconsolidated such as sands and gravel (Morgan, 2001).

Organic and chemical constituents of soil are important because of their influence on stability of aggregates. Soils with less than 2% organic matter can be considered erodible (Boardman, 2006; Martins *et al*., 2012).

Infiltration is the movement of water into the immediate soil surface. It is an important component in watershed modeling for the prediction of surface runoff (Rahman, 2010; Al-Janobi *et. al*. 2010). For a given soil, the land use pattern play a vital role in determining the infiltration characteristic and is of particular interest to soil scientist, hydrologist, agronomist, geographers and agricultural engineers. Two essential parameters used in characterizing infiltration of water into soil profile are rate and cumulative amount (Akintoye *et al*. 2012; Anikwe and Ubochi, 2007). Measurement and numerical solutions have shown that infiltration rate in a uniform, initially dry soil when rainfall does not limit infiltration, decrease with time and approaches an asymptotic minimum rate (Runbin *et. al*., 2011).

Isolation of the effects of land use treatments will enable an assessment of infiltration capacity under different land uses in a given watershed. Such effects are realizable by the two terms of sorptivity, S and the A, parameter of the Philips equation. It state that:

$I = St^{½} + At$ ……………………………2

Where:
I = the infiltration rate in mm/hr
S = Asorptivity and
A = transmission properties of the soil.

The study looks at the physical properties of some soils on erodibility and infiltration parameters of some selected areas in Gidan Kwano and compare the infiltration rate of the selected points.

Materials and Methods

Study Area

The Federal University of Technology, Minna, Gidan Kwano is located along kilometer 10 Minna – Bida Road, South – East of Minna in Bosso Local Government Area of Niger State with a total land mass of eighteen thousand nine hundred hectares (18,900 ha). It has a horse – shoe shaped stretch of land, lying approximately on longitude of 060 28‟ E and latitude of 090 35‟ N. The site is bounded Northwards by the Western rail line from Lagos to the northern part of the country and the eastern side by the Minna – Bida Road and to the North – West by the Dagga hill and river Dagga (Musa *et al.*, 2013). Figure 1 show the extracted study area from the map of the permanent site of the Federal University of Technology, Minna, Nigeria.

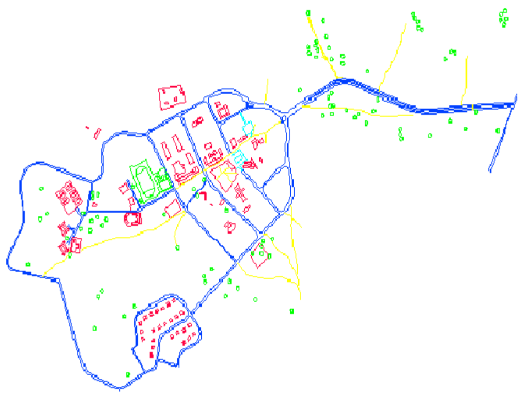

Fig. 1: Map showing selected study areas in dotted green within the main campus of Federal University of Technology, Gidan Kwano.

Field Works

Twelve soil samples from 0-30 cm and 30-60 cm depths of uncultivated farmland with an auger from two different plots within the study area. Six samples were collected randomly from each plot. The distance from one sample to another is measured to be 10 m at each plot. 450 g of the soil sample were put into polythene and were properly labeled and taken to the laboratory.

Soil structure

Soil structure was determined by physically examining column of undisturbed soil samples collected using the core sampler. The relative sizes of particles, aggregation, pedform, and entire structure in terms of grade, form, structure and size were precisely analyzed.

Particle size analysis.

The hydrometer method was used to determine the particles sizes analysis. 50 g of soil sample from a 2 mm sieve was poured in a conical flask. 50 ml of sodium hexametaphosphate was added to the soil sample in the flask after which 100 ml of distilled water was added. The solutions were mechanically shaken and stirred to allow the particles to disperse well but not done in such a manner as to reduce the sizes of soil particles, and was allowed to stand for 24 hours. This is in accordance with the works of Panagos *et al*., (2014). After 40s, the hydrometer was introduced into the cylinder and allowed to stabilize before taking the reading. The solution was kept for 2 hours after which another reading was taken using the hydrometer. The temperatures readings were taken for each of these two processes. The first reading of temperature (T_1) and hydrometer (H_1) were used to calculate the percentage sand content, while the second reading of temperature (T_2) and hydrometer (H_2) were used in calculating the percentage clay content. This is in accordance with the work of Kim *et al*., (2011). According to Dagadu and Nimbalkar (2012), a correction factor in relation to the temperature is added to the hydrometer readings giving new values of H_3 and H_4 respectively.

$$\% \text{ Sand} = 100 - \frac{(H_3 x\ 100)}{\text{Weight of Soil}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ 3$$

$$\% \text{ Clay} = \frac{(H_4 x\ 100)}{\text{Weight of Soil sample}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..4$$

$$\% \text{ Silt} = 100 - (\% \text{ sand} + \% \text{ Clay}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Soil textural triangle

Soil texture triangle gives names associated with various combinations of sand, silt and clay. A coarse-textured or sandy soil is one comprised primarily of medium to coarse size sand particles. A fine-textured or clayey soil is one dominated by tiny clay particles. Due to the strong physical properties of clay, a soil with only 20% clay particles behaves as sticky, gummy clayey soil. The term loam refers to a soil with a combination of sand, silt, and clay sized particles.

Moisture content

Determination of water content in the various soil samples were carried out using gravimetric method. A 78g portion of the samples collected oven dried at a temperature of 105 ^{o}C for 24 hrs. This is in accordance with the work of Dexter (2004).

The initial weight of the container W_1 was determined and 78 g soil sample put up to half of the container and was weigh again as W_2. And it was put in the oven for 24 hrs at a constant temperature of 105 ^{o}C. After which the soil sample and the container were weighted as W_3.

The moisture content was calculated using the following relation.

$$M_c\% = \frac{W_2 - W_3}{W_3 - W_1} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ 6$$

Where:
M_c = moisture content.
W_1 = weight of container.
W_2 = weight of container and sample.
W_3 = weight after oven dry.

BULK DENSITY

Using a core sampler, soil samples were collected at depths 0 - 30 cm and 30- 60 cm depths respectively under each tillage system on the sites. The total sample in the core samples were transferred into nylon and were conveyed to the laboratory.

In the laboratory, the mass of each empty crucible was found, (M_I). The soil sample was then transferred from the nylon into the crucible and then reweighed as (M_2).The crucible with the soil samples were kept in the oven for 24 hrs at 105 ^{o}C for total dryness of the moisture in the soil sample. After, which the crucibles were then removed from oven and then reweighed as (M_3). From this, the bulk density was calculated as mass of oven dried soil per volume of core (g\cm^3) and gravimetric water content as mass of water in the soil sample per mass of the oven dried soil.

$$\text{Bulk density} = \frac{\text{Mass of oven dry soil}}{\text{Volume of core}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.7$$

Soil color

The colors of the collect samples were carefully examined in the laboratory using the Munsell soil color chart, 1975 edition. The chart provides tables of colors to compare colors different moist soils samples. The Munsell system of colors uses three dimensions of color (hue, value, and chroma). The Hue color is the dominant spectral color of the soil and is related to wavelength of the light(a specific color) while the Value is a number that refers to the relative lightness of color (lightness and darkness) and the Chroma refers to the number showing the relative purity of the dominant color(color intensity). The notations were recorded as hue, value/chroma. For example, 10Y 3/6 indicates that the soil has a hue of 10Y, value of 3 and chroma of 6. The collected moist soil samples were carefully examined under the Hue 10YR Munsell system of color by holding the soil sample next to the different chips color box in the Munsell color chart to get a visual match in other to assign the appropriate Munsell notation. For example, a dark yellowish brown soil may be noted as: hue value/chroma (10Y 3/6).

Infiltration rate

A Double-ring infiltrometers were used. The rate of reduced water was measured in the inner ring. One double-ring infiltrometers were set up at each plot. The diameters of the inner outer rings were 30 cm and 60 cm respectively (Ieke *et al*., 2013; Musa and Egharevba, 2009; Diamond and Shanley, 2003). They were driven into the ground to about 15 cm and 30 cm depth respectively. The inner and outer edges were tamped to seal possible cracking. Generally the water level was measure at an interval of 5 minutes. The rate of fall of the water level in the inner cylinder was measured at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 60 etc. minutes to determine the rate of water intakes of the soil. This rate becomes constant when the saturated infiltration rate for the particular soil has been reached.

Soil Erodibility Determination

This was determined using the method stated in the works of Anache *et al*., (2015) and Idah *et al.,* (2008). The method of field test developed was used to determine soil erodibility. Samples were collected from depths ranging from 0-30 and 30-60 centimeters for soil structural classification.

Results and discussion

Soil aggregates

Table 1 presents the results of the soil aggregates for the selected plots within the study areas of the Federal University of Technology, Minna, Gidan Kwano. Placing the respective percentages of sand, silt and clay particles on a textural triangle, the soil in the selected area can be classified into following textural classes. Soil aggregation is essential for the resistance of land surfaces to erodibility, and it influence the capacity of soils to remain productive (Pinheiro, *et al.*, 2004). The results obtained from Bougocous hydrometer method showed that the plot B has higher percentage of sand compared to plot A. The percentage of sand of each soil sample from plot B, range from 51% to 62% while that of plot A, range from 41% to 51%. Similarly the clay content of plot B is higher than that of plot A while the silt contents of plot A is higher than that of plot B. This result shows that plot A is most suitable for crop production than plot B. According to the work of Afolabi *et al.,* (2014), the percentage of sand recorded was very high ranging 68% - 76% and 74% - 79% when compared to this result for the respective soil condition.

Table 1: Soil particles size and textural classification result of selected areas.

		Particles size			
Plots	Samples	% Sand	% Silt	% Clay	Textural class
A	1	51	35	14	Medium Loam
	2	41	38	21	Medium Loam
	3	44	36	20	Medium Loam
B	1	62	12	27	Sand Clay Loam
	2	51	10	40	Sand Clay
	3	57	17	27	Sand Clay Loam

Infiltration parameters

Figures 2 and 5 shows the results of the infiltration rate carried out on the selected plots of the study area. It was observed that plot B infiltrates faster than plot A, which is because the soil particles of plot B were dry when compared to plot A. Thus Shape, size and stability of soil aggregates may affect the absorbance rate of rainwater and infiltration rate. Coarse-grained sandy soils are known to have large spaces between each grain which allows water to infiltrate quickly; this is in accordance with the work of Ieke *et al.,* (2013). Infiltration rates of soil decrease over time until a steady state is reached. In addition, the infiltration is dependent on several factors, including soil texture, structure, initial soil water content, pore size, soil metric potential and vegetation (Al-Janobi *et al*., 2010). This behavior is also reflected in the cumulative infiltration show a rapid increase in the volume of water infiltrated within a short times, which increases gradually to a nearly linear rate over the period of time as shown in the Figures 3 and 6 respectively. Several researchers have shown that sandy soil has a higher infiltration rate than clay soil under identical conditions (Runbin, 2011). The available volume for additional water in the soil depends on the porosity of the soil and the rate at which infiltration rate occur from the surface of the soil. If the amount of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, pounding begins and is followed by runoff over the ground surface which will eventually bring about the washing away of the soil particles. Soil erodibility is the resistance of the soil to both detachment and transport which is a function of soil texture, structure, permeability, organic matter content etc. (Harris *et al., 2012,*). From this study, the infiltration rate became steady at 70 minutes in plot A and 55 minutes in plot B before it eventually tends to a steady state.

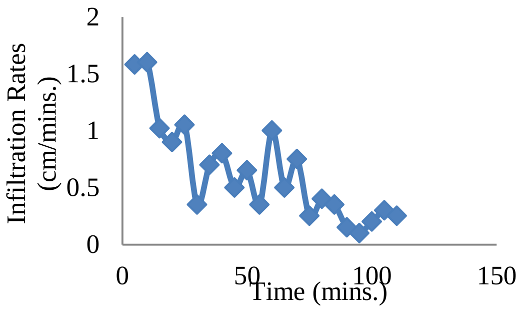

Figure 2: Infiltration Rate graph of plot A

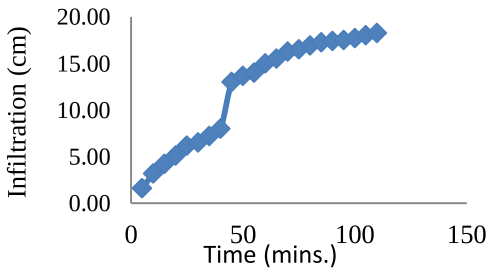

Figure 3: Cumulative Infiltration of plot A

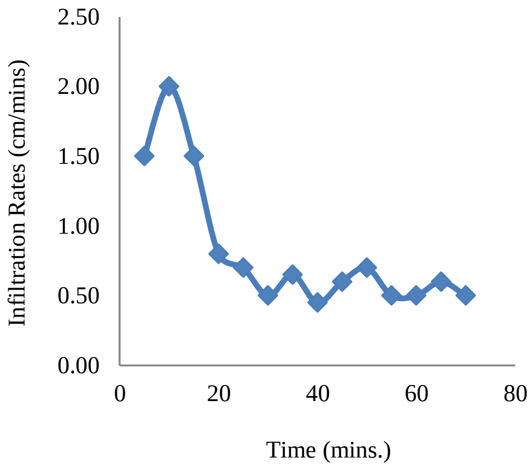

Figure 4: Infiltration Rate graph of plot B

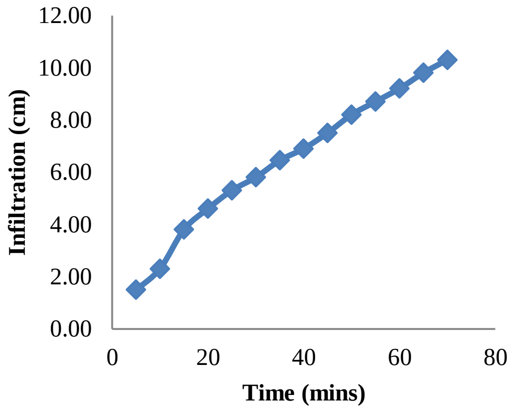

Figure 5: Cumulative Infiltration of plot B.

Soil moisture contents

Table 1 and 2 below presents the results of the moisture content of the selected study areas. The results shows that the average moisture content of the plots A and B range from 9.55% to 14.55% and from 10.65% to 11.25% respectively. This result were similar to the initial work carried out at a different location of the same study area by Musa and Egharevba, (2009) whose moisture contents ranged between 10% and 13%. The degree of dryness of the soil within the study areas when compared with the results of Andreassian *et al*., (2004), it confirmed that infiltration rate is higher for dry soil. It has been established by several researcher that low moisture reduces the cohesiveness among the particles thus making them freely dispersible by water and other erosion agents, thereby making it vulnerable to erodibility. This is in accordance with the work of Andreassian *et al*., (2004), Knapen *et al*.,(2007) and Ajalloeian *et al*.,(2012).

Table 2: Moisture content of Plot A

s/n	Samples	Soil depth (cm)	Weight of containe (g)	Weight of cont.+ sample (g)	Weight after oven dry (g)	Moisture content (%)	Average Moisture content (%)
1.0	1	0 – 30	25.529	103.339	93.408	14.6	14.55
2.0		30 – 60	25.168	103.605	93.674	14.5	
3.0	2	0 – 30	25.073	103.851	93.532	15.1	9.55
4.0		30 – 60	24.941	103.515	100.518	4.0	
5.0	3	0 – 30	24.904	103.852	95.476	11.9	11.60
6.0		30 - 60	22.881	101.131	93.202	11.3	

Table 3: Moisture content of plot B

s/n	Samples	Soil depth (cm)	Weight of container (g)	Weight of cont.+ sample (g)	Weight after oven dry (g)	Moisture Content (%)	Average Moisture content (%)
1.0	1	0 – 30	26.333	104.740	96.570	11.6	10.65
2.0		30 – 60	25.023	103.314	96.422	9.7	
3.0	2	0 – 30	24.907	103.410	95.639	11.0	10.95
4.0		30 – 60	24.676	103.110	95.403	10.9	
5.0	3	0 – 30	25.986	103.101	94.337	12.8	11.40
6.0		30 - 60	24.918	103.476	96.333	10.0	

Bulk Density and Particle Density

The highest value of bulk density and particle density was found in plot A as observed from Table 3 which ranges between 1.36 gcm^{-1} and 1.71 gcm^{-1} while that of plot B ranged between 1.40 gcm^{-1} and 1.45 gcm^{-1}. This is similar to the works of Musa and Egharevba (2009) and Musa *et al*., (2013).

Organic Matter (OM)

Soil organic matters (OM) in the various locations are different. The Soil organic matters range from 3.95% to 4.10% in both plots. This results show that, if OM is increased the soil infiltrability tend to increased. This is also in accordance to the work of Leonard *et al*., (2006), Lipiec *et al.,* (2006) and Savadogo *et al.,* (2007).

Soil Porosity

Several researchers have identified that the rate of soil moisture movement affects the nutrients solubility and water distribution in the soil. The ability of soil to store water depends on the soil porosity, as water moves faster through macro-pores on sandy soils than clay soil. The result of the soil analysis shows that, the soil storage capacity depends on the available pore spaces. Plot B which is mostly sandy soil has a high porosity making it difficult to store available water. The water moves more quickly through macro-pores on sandy soils. This is in accordance to the work of Ieke *et al.,* (2013).

Table 3: soil aggregates results of Plot A

Sample	Depth (c)	Particle Size			Bd (gcm^{-1})	Pd (gcm^{1})	P (%)	OC (%)	OM (%)
		% Sand	% Silt	% Clay					
1	0-30	59	28	13	1.45	1.56	7.05	2.5	4.3
	30-60	43	42	15	1.26	2.94	57.1	2.1	3.6
2	0-30	42	39	19	1.80	2.80	35.7	2.7	4.6
	30-60	40	38	22	1.61	2.90	44.5	2.1	3.6
3	0-30	48	33	19	1.52	1.99	23.6	2.6	4.5
	30-60	40	39	21	1.44	3.10	53.5	2.0	3.4

NOTE: Mc = Moisture content, Bd = Bulk density, Pd = Particle density, P = Porosity, OC = Organic carbon and OM = Organic matter.

Table 4: Soil Aggregates Results of Plot B

Sample	Depth (cm)	Particle Size			Bd (gcm^{-1})	Pd (gcm^{-1})	P (%)	OC (%)	OM (%)
		%Sand	%Silt	%Clay					
1	0-30	57	20	23	1.39	1.70	18.2	1.8	3.1
	30-60	66	3	31	1.51	1.89	20.1	2.8	4.8
2	0-30	53	9	38	1.40	1.78	21.3	2.3	4.0
	30-60	48	11	41	1.43	1.80	20.6	2.0	3.4
3	0-30	48	30	22	1.28	1.82	29.7	1.8	3.1
	30-60	42	25	33	1.45	1.91	24.1	1.5	2.6

NOTE: Mc = Moisture content, Bd = Bulk density, Pd = Particle density, P = Porosity, OC = Organic carbon and OM = Organic matter

Soil colour

The colour formation observed in each of the study location is presented in Table 5. Plots A and B soil samples are dominated by dark yellowish brown color which is noted as 10Y 3/6, 10YR 3/4 .This was in accordance to the work of (Lynn *et al., 2000*). The colors of soil are derived largely from organic matter and minerals. Spring (2006), stated that, dark brown to black colors at or near the surface of a soil profile generally indicate an accumulation of organic matter (humus). Thus, yellow and reddish-brown colors may indicate the soil is well drained and well aerated.

Table 5: Color of soil Samples

s/n	Plots	Samples	Depth (cm)	Color code	Color name
1.0	Plot A	1	0 – 30	10YR ¾	Dark yellowish brown
2.0			30 – 60	10YR 3/6	Dark yellowish brown
3.0		2	0 – 30	10YR 3/6	Dark yellowish brown
4.0			30 – 60	10YR 5/6	Yellowish brown
5.0		3	0 – 30	10YR 5/6	Yellowish brown
6.0			30 - 60	10YR 5/6	Yellowish brown
7.0	Plot B	1	0 – 30	10YR ¾	Dark yellowish brown
8.0			30 – 60	10YR 4/4	Dark yellowish brown
9.0		2	0 – 30	10YR 3/1	Very dark gray
10.0			30 – 60	10YR 3/3	Dark brown
11.0		3	0 – 30	10YR 3/6	Dark yellowish brown
12.0			30 – 60	10YR 4/6	Dark yellowish brown

Erodibility Index

Table 6 presents the erodibility index of the selected plots. Soil erodibility factor (K) is a quantitative description of the inherent erodibility of a particular soil as it measures the susceptibility of the soil particles to detachment and transportability by rainfall and runoff. This factor reflects that different soils erode at different rates when the other factors that affect erosion are same (Mulumba and Lal, 2008). The determined erodibility indexes of the various plots were highly negative which means that the soil is highly erodible with that of plot B much higher than that of plot A. This is similar to the works of Igwe (2003); Rhoton *et al*., (2007) and Gajic *et al*., (2013).

Table 6: Erodibility Index for the various plots

Plots	Samples	Depth (cm)	Erodibility Index (K)
A	1	0-60	-121.46
	2	0-60	-126.83
	3	0-60	-131.34
B	1	0-60	-145.24
	2	0-60	-815.99
	3	0-60	-108.51

Conclusion

The determination of the soil physical properties and its effects on erodibility and infiltration rate of soils in selected areas of the Federal University of Technology, Minna, Gidan Kwanu Campus was carried out and various results obtained. The particle size analysis showed that the soils type in plots A and B was medium loam and sand clay loam respectively which makes them susceptible to erosion as the rate of infiltration into the soil is slow. The double ring infiltrometer used in the computation of the infiltration rate shows that plot B has a high rate of infiltration compare to plot A. Plot B has approximately the same moisture content compare to plot A which varies. The sample with the least moisture content was obtained in plot A (sample 2), having average moisture content of 9.55%. It is therefore concluded that the soil within the study area have poor infiltration rate which leads to the ponding of water is come depressions in the study area and later, the occurrence of surface runoff. During which fine soil particles are carried away.

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